Application and efficiency of beeswax casting and digital photogrammetry to study the morphology of a *Varanus* sp. foraging excavation

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ABSTRACT

This project assessed the value of wax casting, digital modelling and photogrammetry to model and measure a *Varanus* sp. digging. European honeybee wax proved to be a versatile and practical medium for casting the digging as it was robust to transportation, required no added liquid or onsite preparation and was easily melted and poured. Although solid, the resulting cast was not brittle and was not damaged during excavation, transportation and measurement. The volume of the cast was quickly and easily determined via weighing, fluid displacement and photogrammetry and the three volume measures varied by only 3%. The primary value of the cast was that it could be inverted and placed under a good light source for close examination, measurement and photography. The digital model of the digging was visually detailed and instantaneously showed measurements, including volume, surface area and maximum length, width and depth. Mechanical and photogrammetric linear measurements made on the surface of the cast and digital model were statistically identical. The principal cost of the digital modelling was the time required to learn to use the software and complete the modelling (42.5 hours). Therefore, this technique may only be feasible for studies of close range morphology or where parameters that can not otherwise be easily obtained, such as surface area and contours, are required.

Key words: fauna digging morphology, beeswax casting, *Varanus* sp., casting, digital modelling, photogrammetry.

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Introduction

Measurement of the morphology of animal excavations is an important component of the study of the ecological role of digging fauna. This is because the morphology of diggings and burrows varies widely between species (and / or groups of species), and the ecological effects of the excavations varies with their morphology (see reviews by Whitford and Kay (1999) and Eldridge and James (2009)).

The suite of techniques currently used to measure the morphology of fauna diggings and burrows includes excavation and physical measurement (Smyth and Philpott 1968; Verdolina *et al.* 2008), modelling of dimensions in relation to a known bulk soil density (Eldridge and Mensinga 2007; Eldridge and Kwok 2008; James and Eldridge 2007; Newell 2008), mathematical modelling via geometric shape projection (Bancroft *et al.* 2004) and casting with expanding polyurethane foam (Felthauser and McInroy 1983; Reynolds and Wakkinen 1985) and wax (Lim and Diong 2003). Each technique has advantages and limitations.

For example, excavation and physical measurement may cause damage, so that some parts of the digging or burrow cannot be identified or measured. Modelling of dimensions in relation to a known bulk soil density has been shown to be more than 90% accurate (James and Eldridge 2007) for measuring volume, but is not suitable for studying detailed morphology. Casting fills the entire space, including the parts which cannot be viewed, accessed and physically measured. It also facilitates accurate measurement after excavation. However, its use is limited by the logistics of storage, transport, preparation and pouring of the casting medium (Bancroft *et al.* 2004).

Photogrammetry is an emerging technique that, to the author's knowledge, has yet to be tested for the study of animal excavations. It is a means of measuring morphology using computer based 3 dimensional (3D) digital models of objects or scenes. After calibration, a standard digital camera is used to take two or more photographs of the object or scene. The photographs are imported into the software, where they are processed and a 3D 'map' of the surface is produced using thousands of points, for which the x, y and z co-ordinates are calculated via a co-linearity equation (García *et al.* 2002; Luhmann *et al.* 2006; Yilmaz and Yakar 2008; Yilmaz *et al.* 2008). The technique is similar to laser scanning but uses light rays, instead of laser beams, to determine the positions of points on the surface of the object or parts of the scene (Luhmann *et al.* 2006). A scale digital model is then produced by fitting a surface to the points via triangulation and it can then be measured via photogrammetry.

Common applications for photogrammetry include engineering, architecture, geomorphology, archaeology and motor vehicle accident investigation (Luhmann et al. 2006). Trials have also been conducted for biological applications such as morphological studies of museum specimens (Chiari *et al.* 2008), measurement of coral surface area (Bythell *et al.* 2001) and measurement of the mass of marine mammals (de Bruyn 2009). The technology has proven to be an accurate, non-destructive and convenient means of representing and storing morphometric information. However, it can also be time consuming (Bythell *et al.* 2001; Chiari *et al.* 2008) and this may be one of its primary limitations.

This project investigated the application and efficiency of using two techniques to represent and measure the morphology of a fauna foraging digging. Wax casting and photogrammetry were used to model and measure a *Varanus* sp. digging. The time taken to gain the skills to build the digital model and measure the cast and the model was recorded. The costs and benefits of both techniques are discussed.

Methods

This study was conducted at the former Lorna Glen Station (Matuwa), about 1,100 km northeast of Perth, in Western Australia's arid rangelands. Lorna Glen is a 244,000 ha proposed conservation reserve, about 160 km ENE of Wiluna and is managed by the Department of Environment and Conservation, in conjunction with the Martu Aboriginal community from Wiluna. Lorna Glen is in the Murchison soil landscape province, which is characterised by extensive plains with residuals of laterites or Precambrian igneous rocks (Betteny 1983). The major soils are red and brown hardpan soils, red earths and red sands (Betteny 1983; Mabbutt 1963). Vegetation associations in the area include hummock grasslands, low acacia woodland and shrubland, succulent steppe and other mosaics (Mabbutt 1963).

A fresh foraging digging was located at the base of a spinifex grass *Triodia melvillei* (Fig. 1) on 10 May 2011. The animal responsible was not seen making the digging and thus it may be attributed to either Gould's Goanna *Varanus gouldii* (J.E. Gray, 1838) or the Yellow-spotted Monitor *Varanus panoptes* (Storr, 1980) (CAVS 2006; Clayton *et al.* 2006), which are similar in size and morphology (Cogger 2000).

Casting

Bullions (30 g each) of beeswax were melted in a pot on a camp stove which was shielded from the wind, placed in an area clear of vegetation and attended at all times while in use. The hot wax was decanted into a smaller vessel with a pouring lip and poured over a folded piece of paper to prevent soil erosion by the wax stream. The digging was filled with wax to the level of the surface of the surrounding undisturbed soil (Fig. 1). The cast was excavated using a trowel on the following day and soil and plant material that had adhered to the surface of the cast was removed by hand and using a banister brush. The cast was then wrapped in newspaper and packed in cardboard for transportation.

Figure 1. Dried wax in the digging at the base of the spinifex grass *Triodia melvillei* located at 26° 12' 01.6" S, 121° 34' 0.4" E (WGS 84). For scale the maximum length of the base of the cast was c. 175 mm.

Digital modelling

Photomodeler Scanner® 2011 software (EOS Systems Inc.) was used to produce a digital model of the cast. First, a standard digital camera (Ricoh G700SE) was calibrated to determine its parameters, including focal length, projection centre and lens distortion. Calibration involved photographing a sheet of A4 paper printed with coded targets and point markers, which was provided with the software. The photographs were imported into the software and processed via a calibration wizard. The software indicated that the camera calibration had been successful and the resulting calibration file was saved for use during subsequent modelling projects using the same model of camera.

The cast was inverted and placed on a sheet of paper with coded targets (provided with the software) printed on it (Fig. 2). The coded targets are not essential, because the software can identify points on the surface of the object, provided it varies in colour and texture (Eos Systems Inc. 2010). However, the targets are useful for identifying and orienting the surface below the cast and scaling the model using the known distance between the points in the centre of the targets (in this case 18 mm). Although the camera can be moved around the object between shots, the object must not be moved between photographs (Eos Systems Inc. 2010).

Eighteen overlapping photographs of the cast were taken and imported into the software. Surface point maps were then produced by the software which detects and matches points on pairs of photographs (Eos Systems Inc. 2010). The resulting 45 point maps were combined into a single point map of the surface of the cast. The software was used to remove outliers, interpolate holes in the surface, triangulate the points and place contours on the model (Fig. 3). The model was then scaled and oriented to the x, y and z axes using a software wizard.

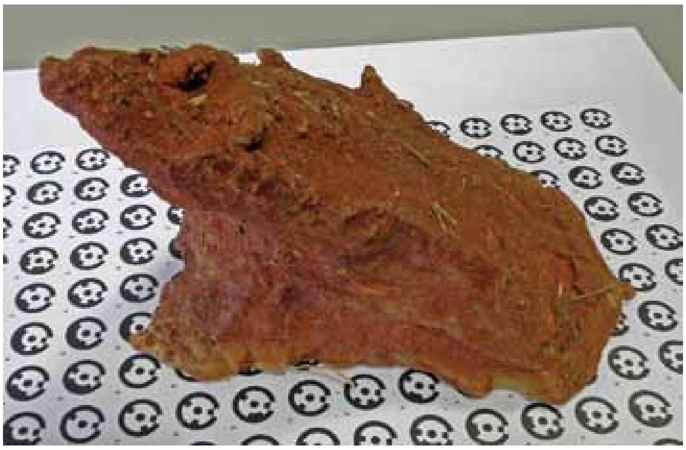

Figure 2. Inverted cast placed on coded targets for photographing.

Figure 3. Surface of the model represented by 3D points, showing contours at 20 mm intervals.

Morphological measurements

Three methods were used to measure the volume of the digging. First, the cast was weighed, and its volume was extrapolated from its weight using the known bulk density for beeswax of 0.961 g/cm^3 (Hossain *et al.* 2009; Lewis 2002). Second, it was lowered into a volumetric cylinder containing water and the volume of water displaced was recorded on the gradational scale. Finally, the volume of the digital model was displayed in the measurements window of the software by clicking on the surface (surface area was also displayed). Variation in the three volume measurements was examined using coefficient of variation.

Linear measurements were made on the wax cast and the digital model of the cast and the two datasets were compared using Spearman rank correlation. The maximum length, width and depth of the cast were measured using callipers and then the same measures were obtained from the software by clicking on the surface with the measurements window open. Twenty linear measurements were made between arbitrarily selected points on the wax cast using digital callipers with 0.01 mm accuracy, and the same points were then identified, marked, cross referenced between two photographs, and measured on the digital model using the software. Each calliper and digital measurement was made sequentially, with the calliper measurements first, so that the digital measurements could not influence the mechanical measurements.

Time investment

The time taken to learn to use the software and obtain the measurements was recorded to the nearest 5 minutes.

Results

Time investment

Measurement of the maximum depth, width and length of the cast using callipers took 5 minutes. Determination of volume of the wax cast by weighing took 10 minutes, and by water displacement took around 25 minutes. Digital modelling, software experimentation and viewing of online tutorial videos took around 35 hours and 20 minutes (Table 1). Photography and digital processing took around 7 hours and 10 minutes (Table 1). Sequential measurement of the linear distances on the wax cast and on the digital model took around an hour (Table 1) because of the requirement to cross reference points between photographs prior to photogrammetric measurement. Measures for the maximum dimensions and surface area of the digital model were displayed instantaneously in the measurements window of the software by clicking on the surface of the model.

Table 1. Time taken to photograph the cast, learn to operate the software, construct the digital model and obtain the comparative linear measures (to the nearest five minutes).

Task	Time (hh:mm)
Photography of cast	0:20
Viewing tutorial videos	1:30
Experimentation and software testing	33:50
Digital processing	6:50
Measuring (wax cast and digital model sequentially for 23 linear distances)	1:05
Total	**43:35**

Surface model

The surface point map of the cast contained 42,900 points (refer to Fig. 3), and the surface triangulation contained 85,300 triangles. When fitted with a surface, the model was visually detailed (Fig. 4) and it could be rotated, magnified and viewed from any angle using the software. Other parameters, such as the angle of incidence of the digging floor and length of the contours can be determined by exporting a model data file to computer-aided design or geographic information software (author's observations).

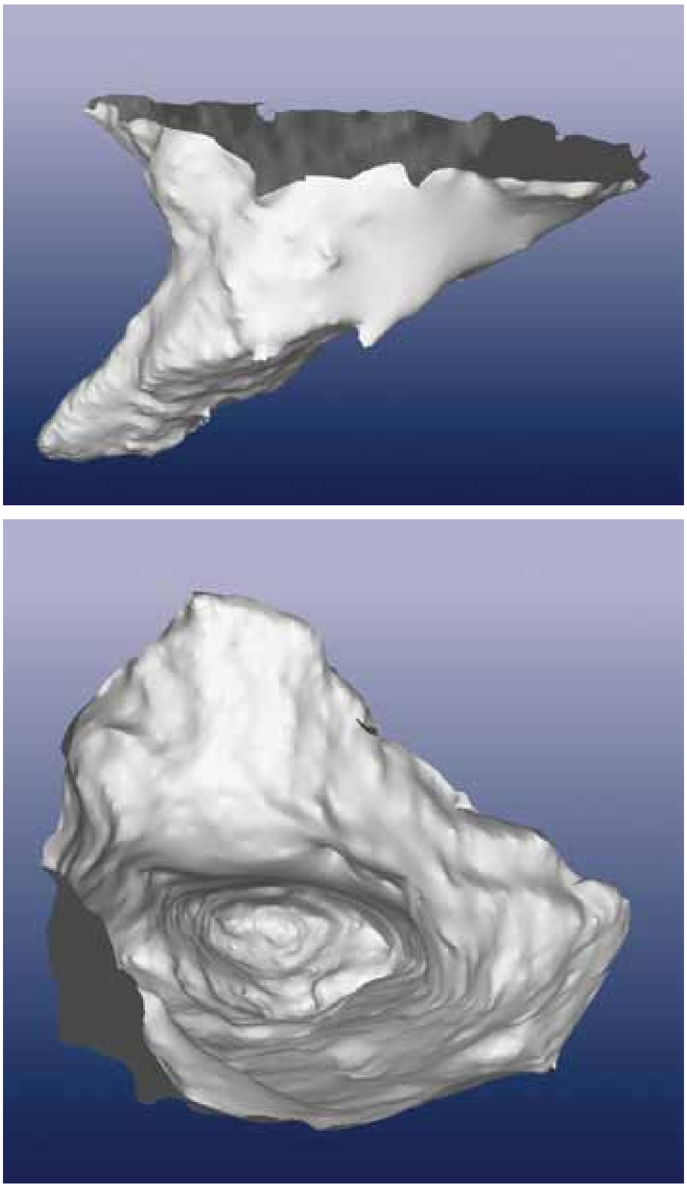

Figure 4. Digital model of the digging surface from two angles.

Morphological measurements

The volume of the cast was measured at 552.5 cm^3 using bulk density, 530 cm^3 using water displacement and 560.259 cm^3 using photogrammetry. The three values had a mean of 547.59 cm^3, a standard error of 9.07 cm^3 and coefficient of variation of 2.87%. Using triangulation, the surface area of the model was calculated by photogrammetry at 369.30 cm^2. This measurement could not accurately be obtained by any other means.

Table 2 shows a comparison of the maximum depth, width and length and 20 linear distances between selected points measured by callipers on the wax cast and by photogrammetry on the digital model. The mean of the difference for the two datasets was 0.49 mm (s.e. 0.26 mm) and the mean percent difference was 0.49% (n = 23). The mechanical and digital measurements were strongly correlated (Correlation coefficient = 1.000, P < 0.0001).

Table 2. Comparison of linear measurements (mm) obtained by callipers on the wax cast and by photogrammetry on the digital model.

Measure	Wax cast	Digital model	Difference
Maximum depth	112.55	115.36	2.81
Maximum width	114.43	116.40	1.97
Maximum length	172.22	177.54	5.32
1	69.06	70.88	0.18
2	201.02	204.17	0.37
3	28.72	29.60	0.10
4	35.45	36.75	0.05
5	22.95	22.91	0.01
6	30.87	31.33	0.03
7	26.13	27.71	0.01
8	57.65	58.92	0.12
9	58.25	59.25	0.15
10	129.55	131.91	0.21
11	71.33	72.70	0.10
12	40.71	42.13	0.13
13	15.89	15.74	0.04
14	99.55	101.76	0.16
15	24.8	24.69	0.09
16	102.57	104.99	0.19
17	137.32	138.43	0.23
18	147.52	148.90	0.30
19	59.47	60.66	0.16
20	55.92	57.84	0.14

Discussion

European honeybee wax proved to be a versatile and practical medium for casting the *Varanus* sp. digging in this study and has since been used by the author to cast the diggings of native golden bandicoots *Isodon auratus*, bilbies *Macrotis lagotis* and introduced European rabbits *Oryctolagus cuniculus* at Lorna Glen. The wax was robust to transportation, required no added liquid or onsite preparation and was easily melted and poured. It did not set too rapidly during pouring and although solid, the resulting cast was not brittle and was not damaged during excavation, transportation and measurement.

The primary value of the cast was that it could be inverted and placed under a good light source for close examination, measurement and photography. This completely overcomes the problem of insufficient access and light when attempting to measure diggings in the field. The resulting digital model was visually detailed and facilitated instantaneous measurement of parameters, including those that could not easily be obtained via mechanical means, such as surface area and contours. Similar to other studies (Bythell *et al.* 2001; Chiari *et al.* 2008; de Bruyn 2009), the photogrammetric measurements obtained in this study were statistically identical to the mechanical measurements.

The volume of the cast was quickly and easily determined via weighing, fluid displacement and photogrammetry (excluding model production). Some error would be expected in the mechanical volume measurements due to the small amount of soil and plant material and water that had adhered to the cast. However, since the volume measurements varied by only 3%, all three could be considered accurate and efficacious, at least for casts the size of the one in the present study.

One potential application of modelling and photogrammetric measurement is morphological modelling of diggings of known origin and using quantitative parameters to indentify the most likely species to have made diggings of unknown origin. If this is possible, it could increase the number of diggings that can be attributed to a species since, at present, some diggings cannot readily be identified by sight (James and Eldridge 2007; Newell 2008). Another potential application is assessment of water infiltration processes, because extrapolation of infiltration over broader scales is dependent on determining the surface area of the digging; a parameter that is not easily obtained by conventional means.

The principal, and not insignificant, cost of digital modelling and photogrammetric measurement in this, and the other studies (Bythell *et al.* 2001; Chiari *et al.* 2008), was the time required to learn to use the software and complete the modelling (in this study 42.5 hours). Therefore, it may only be feasible for detailed close range studies of digging morphology where parameters that can not otherwise be easily obtained, such as surface area and contours, are required. It would be expected, however, that once the operator is trained in the use of the software, the processing and measurement would become significantly faster. Despite the initial time cost required to operate the software, photogrammetry has the potential to become an important tool in the range of techniques currently used to study the morphology of animal diggings.

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